(19) Europäisches Patentamt
European Patent Office
Office europ´en des brevets

(11) Publication number: **0 618 619 A1**

(12) EUROPEAN PATENT APPLICATION

(21) Application number: 94200577.8

(51) Int. Cl.5: H01L 23/373

(22) Date of filing: 07.03.94

(30) Priority: 29.03.93 US 38379

(43) Date of publication of application: 05.10.94 Bulletin 94/40

(84) Designated Contracting States: DE ES FR GB

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(54) Ultra-thick thick films for thermal management and current-carrying capabilities in hybrid circuits.

(57) Disclosed is an ultra-thick thick film (30) of copper or silver or other suitable conductor material for use in spreading heat laterally, i.e., in the x and y directions, along a substrate (32). A substrate (32) of suitable thickness is chosen to dissipate heat in the vertical, i.e., z-direction, underneath a heat-generating component such as a semiconductor chip (26). The ultra-thick films (30) have a thickness ranging from about 50.8µm (2 mils) to about 127µm (5 mils) and are prepared from metal powders having average particles sizes ranging from about 1 micrometre to 3 micrometres.

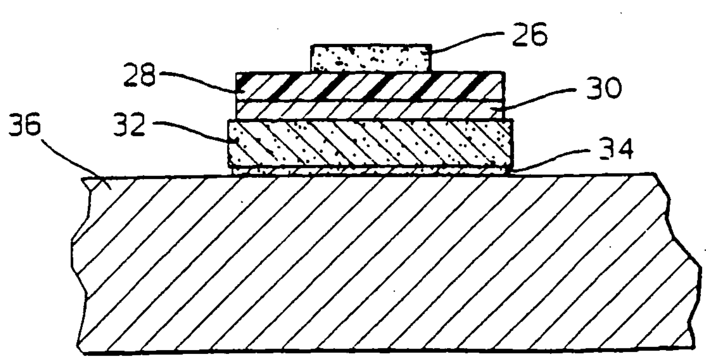

FIG. 2

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This invention relates to micro-electronic devices containing heat-conductive films, and particularly to heat-conductive films used for heat-spreading and high current conduction as specified in the preamble of claim 1, for example as disclosed in US-A-5,121,298.

A variety of methods are known for dissipating heat in semi-conductor devices. An existing method of heat dissipation employs a beryllium oxide (BeO) substrate which has a very high thermal conductivity. In addition, electrical currents may also be conducted by a refractory metallization and solder on the BeO substrate. Disadvantages of such systems include relatively high cost of manufacture, the toxic nature of BeO and relatively high electrical resistance of the refractory metallization. In fact, the use of BeO may not be practical in near future due to anticipated environmental regulation.

Many thermal management methods for semi-conductor applications are designed to dissipate heat primarily in the vertical, termed the 'z-direction' underneath the heat-generating device. For example, alumina substrates are often placed underneath the heat-generating semi-conductor chips. The alumina substrates dissipate heat in the vertical, z-direction away from the heat-generating chip. Such designs are limited in their ability to dissipate heat laterally, i.e., in the x and y directions. This is because the thermal conductivity of an alumina substrate is low compared to metallic materials and the cross-sectional area of the substrate (thickness) available for conduction in the lateral direction is smaller than the area available under the chip for thermal conduction in the z-direction. Systems capable of dissipating heat also in the lateral direction, i.e., the x and y directions, have an advantage over systems capable of dissipating heat only in the vertical, z-direction. Dissipation of heat in the x and y directions is an advantage because it provides low thermal resistance paths in addition to the path directly under the heat-dissipating device which results in an overall reduction in the thermal resistance of the device.

Many semi-conductor heat-dissipating systems primarily use a large substrate or metal core for dissipating heat. The use of thick films for dissipating heat has not heretofore been seriously considered. Conventional thick films have a thickness in the range of about 12.7μm to 25.4μm (0.5 mil to 1.0 mil). It is conventional wisdom to optimise the thickness of such films in the 12.7μm to 25.4μm (0.5 mil to 1.0 mil) range for the intended application. Thicker films are considered to be disadvantageous especially in the cases of nitrogen-fireable copper conductor films where the excessive thickness can lead to improper binder burn-out and can have detrimental effects on solderability and/or adhesion strength. However, it would be desirable to develop a heat-dissipating and current conduction system utilising thick films which is capable of spreading heat in the lateral direction (i.e., in the x and y directions).

A micro-electronic device according to the present invention is characterised by the features specified in the characterising portion of claim 1.

In general, the present invention employs ultra-thick thick films (UTTF) of copper or silver or other suitable electrical conductor material to spread heat laterally, in the x and y directions, underneath a heat-generating semi-conductor device and along the surface of an underlying substrate. The substrate has a thickness suitably chosen to dissipate heat in the z-direction, i.e., the vertical direction. The UTTFs provide for a larger cross-sectional area for lateral heat-spreading than do conventional metallization coatings. The UTTFs also provide a low electrical resistance path for high transient currents up to 75 amperes and steady-state currents of up to 35 amperes on ceramic substrates. This is achieved with the thick film material and as such eliminates special discrete power busses, high-cost metal core substrate materials, or high-cost metallization techniques. The combination of high thermal conductivity and electrical conductivity substantially enhances the capability of alumina-based thick-film circuits for use in high power applications. The UTTFs have thicknesses ranging from greater than 0.0254 mm (0.001") to about 0.127 mm (0.005")

The UTTFs may be prepared by using single or multiple layers of printed films. In the case of multiple printed layers, it is preferable to use a first layer of a high-adhesion composition, and a top layer of a high-solderability composition. The high-adhesion composition includes inorganic binders, and the high-solderability composition contains little or no inorganic binders. For multi-layer UTTFs, it is preferred to fire each layer separately in order to effect complete removal of any organic materials present.

The invention and how it may be performed are hereinafter particularly described with reference to the accompanying drawings, in which:

Figure 1 is an illustration of a prior-art semi-conductor device;

Figure 2 is an illustration of one embodiment of the present invention wherein a UTTF is interposed between a high-power device and a heat-dissipating substrate;

Figure 3 is an illustration of another embodiment of the present invention wherein UTTFs are interposed at various locations in a system for dissipating heat from a high-power device; and

Figure 4 is an illustration of another embodiment of the present invention wherein UTTFs are utilised at various locations on a high-power ceramic circuit utilising a semi-conductor device including bonded wires underneath the device.

Figure 1 shows a prior-art semi-conductor device having a heat-dissipating system. The prior-art device includes a high-power device 10 such as a semi-conductor chip which dissipates heat. Directly underneath the high-power device is a first layer 12 of tin/lead (Sn/Pb) in a weight ratio of 25/75 respectively. Below the first layer of tin/lead (Sn/Pb) is a first metallization layer 14 of molybdenum/manganese (Mo/Mn). Under the first metallization layer is a layer of beryllia (BeO) 16. A second metallization layer 18 of molybdenum/manganese (Mo/Mn) is directly underneath the layer of beryllia. Below the second metallization layer is a second layer 20 of tin/lead (Sn/Pb) in a weight ratio of 60/40 respectively. Under the second layer of tin/lead (Sn/Pb) is a copper buffer 22. Finally, an aluminium backplate 24 is directly underneath the copper buffer. The characteristics of this device are such that heat is dissipated substantially only in the vertical, z-direction underneath the high-power source device. This system does not dissipate heat in the lateral, i.e., the x and y directions, to any considerable degree. This drawback is overcome by the present invention.

One embodiment of the present invention is illustrated in Figure 2. The embodiment includes a high-power device 26 such as a semi-conductor chip which dissipates heat. Directly underneath the high-power device is a tin/lead (Sn/Pb) layer 28 in a weight ratio of 25/75 respectively. A UTTF 30 according to the present invention is placed under the Sn/Pb layer. Below the UTTF is an alumina layer 32. A thermally-conductive adhesive 34 is positioned under the alumina layer. Beneath the adhesive is an aluminium backplate 36. In this embodiment of the invention the Sn/Pb layer typically has a thickness ranging from about 0.0254 mm (0.001") to about 0.178 mm (0.007"). A suitable composition for forming the Sn/Pb layer is manufactured by Delco Electronics Corporation, USA. Similar compositions are commercially available. The alumina layer is 96% aluminium oxide (the remaining portion (4%) is a binder agent) available from Coors Ceramics Company, USA. The alumina layer may have a thickness ranging from about 0.254 mm (0.010") to about 0.889 mm (0.035"), and preferably 0.381 mm to 0.889 mm (0.015" to 0.035"). The thickness of the alumina layer is chosen to optimise mechanical and electrical isolation with good thermal performance.

The thermally-conductive adhesive includes a silicone resin. A suitable adhesive is available from Dow Corning Company, USA, under the trade name DC 6843 or DC 6325. The adhesive may be applied in a thickness ranging from about 0.051 mm (0.002") to about 0.178 mm (0.007"), and preferably 0.127 mm (0.005") . This thickness of the adhesive is chosen so that the adhesive serves a function of mechanical attachment, TCE stress relief between the alumina layer 32 and the aluminium backplate 36, and minimum resistance to heat transfer. The aluminium backplate 36 typically has a thickness ranging from about 1.27 mm (0.05") to about 6.35 mm (0.25")

The UTTF 30, as illustrated in Figure 2, is formed from a composition including a metal powder of copper or silver or other conductive material. The amount of metal powder present in the composition may range from about 80 to about 90 weight percent. Copper UTTFs are prepared from a composition including copper powder having a particle size ranging from about 1 micrometre to about 3 micrometres, and preferably 1 micrometre to about 2 micrometres. The composition includes about 81 percent of copper powder, about 7 percent inorganic binder, the rest being a screening agent. Suitable copper powders are available from Grezes, Inc., Berwyn, PA, USA under the trade name Cu III. Suitable silver inks are available from DuPont Electronics, Wilmington, DE, USA under the trade name DuPont 6160. Preferably the composition used to form the UTTF film includes an inorganic oxide binder present in an amount ranging from about 6.0 to about 7.0 weight percent. Suitable oxide binders are bismuth oxide and copper oxide powders. The UTTF compositions are formulated using conventional techniques known to those skilled in the art.

Preferably, the UTTF is formed by multiple printings of UTTF compositions. The films may be printed using a stencil printing technique. Stencil printing is a process where a brass plate of a suitable thickness is used along with a wire mesh screen. The stencil is used in place of an emulsion coating on the screen. The UTTF is formed to a thickness ranging from about 25.4µm (1 mil) to about 127µm (5 mils), preferably about 50.8µm (2 mils) to about 101.6µm (4 mils).

The copper UTTFs are fired in a nitrogen atmosphere at a temperature ranging from about 900 °C, to about 925 °C, and preferably a peak temperature of about 900 °C. The silver UTTFs are fired in air at a temperature ranging from about 825 °C to about 875 °C, and preferably a peak temperature of 850 °C.

In a preferred embodiment, the UTTF is formed by a bottom layer of a high-adhesion composition formed on an alumina substrate. A high-adhesion composition comprises 81.3% copper powder, 6.8% inorganic binders, and about 12% screening agent by weight. The thickness of the high-adhesion layer may range from about 0.0127 mm (0.0005") to about 0.0762 m (0.003"), and preferably about 0.0508 mm (0.002") thick. A top UTTF layer of high-solderability composition is formed over the bottom UTTF layer. A high-solderability composition comprises 91.8% copper powder and 8.2% screening agent by weight and no oxide binder. The specific screening agent is a mixture of about 90 percent by weight of a solvent,

typically TEXANOL™ (believed to be 2,2,4 Trimethyl 1,3 Pentanediol Monoisobutyrate), and the remainder of a resin, typically ethyl cellulose grade N-50, both of which are available commercially. The high-solderability composition layer may have a thickness ranging from about 0.0127 mm (0.0005") to about 0.0762 mm (0.003"), and preferably about 0.0508 mm (0.002") thick. The high-adhesion composition and high-solderability composition multi-layer UTTF structure is advantageous for copper UTTF compositions.

Figure 3 illustrates another embodiment of the present invention. This embodiment includes the following elements placed underneath each other in the following order: a high-power device 38 such as an integrated circuit chip which produces heat; a first Sn/Pb layer 40 with a weight ratio of 25/75 respectively; a first UTTF layer 42; an alumina layer 44; a second UTTF layer 46; a second Sn/Pb layer 48 with a weight ratio of 60/40 respectively; a copper buffer 50; and an aluminium backplate 52.

Figure 3 has a construction somewhat similar to that of the prior-art device illustrated in Figure 1. However, the prior-art device uses a beryllium oxide layer because of its high thermal conductivity. Ordinarily, an alumina layer used in the present invention (Figure 3) would be avoided because of its lower thermal conductivity. However, the use of UTTF layers overcomes these disadvantages by the lateral spreading of the heat and allowing the vertical dissipation of heat through a larger area of the alumina substrate.

As illustrated in Figure 3, the length, width and thickness of the UTTF layer is chosen to sufficiently provide substantial heat dissipation in the lateral direction, i.e., the x and y directions. For example, for a high-power device such as a semi-conductor chip having a length and width of about 5.08 mm (0.200") and 5.08 mm(0.200"), respectively, the UTTF may have a thickness of about 0.1016 mm (0.004"), width of about 8.382 mm (0.330") and length of about 12.192 mm (0.480").

Figure 4 illustrates another embodiment of the present invention including a semi-conductor chip 54, a solder layer 56, a palladium-silver UTTF layer 58 underneath the solder layer, a silver UTTF layer 80, an alumina substrate 60, a silver UTTF layer 62, a thermally-conductive silicone adhesive layer 64, and an aluminium housing backplate 66 arranged similar to the device of Figure 3. The embodiment further includes an aluminium wire 68 bonded to the chip 54 and to the substrate 60. A silver-palladium UTTF layer 70 is interposed between the aluminium wire 68 and the substrate 60 at the bonding location. The silver-palladium composition used is available from DuPont Company, USA under the trade name DuPont 7484 and includes silver and palladium in a 3:1 weight ratio. The silver-palladium UTTF layer 70 serves to dissipate heat from the wire 68 and provides a reliable bonding surface. The UTTF layers 58, 80, and 62 provide for lateral thermal conduction prior to heat conduction (in the z-direction) through the relatively lower thermal conduction substrate and adhesive layers. The UTTF layers 58, 80, and 70 also provide a low electrical resistance path for high circuit currents. The UTTF layer 62 also improves the total structural thermal conductivity by thinning the relatively lower thermal conduction adhesive layer in the area below the heat-dissipating device. The UTTF layer 62 under the alumina substrate 60 serves to thin the amount of thermally-conductive adhesive 64 between the alumina substrate 60 and the backplate 66, thus improving heat transfer therebetween. The remaining portions of the thermally conductive adhesive 64 are thicker than the portion under the UTTF layer 62, thus providing improved stress-relief between the substrate 60 and backplate 66.

The following examples shown in Tables 1, 2 and 3 illustrate features and advantages of the present invention.

In examples 1-4, UTTF formulations were prepared with copper powder. UTTFs were formed by single or multiple printing of the UTTF's compositions as indicated in Table I. In each case, after a layer is printed, the film was allowed to dry and then fired after each printing. The multi-layer UTTF structures utilised two different copper UTTF compositions. A first copper composition (BC-12) comprised about 81.2 weight percent of copper powder, about 6.8 weight percent of inorganic binder, and about 12.0 weight percent screening agent. A second copper composition (PC-2) comprised about 91.8 weight percent of copper powder, zero weight percent of inorganic binder, and about 8.2 weight percent screening agent. Table I describes the various UTTFs, sheet resistances and resistivities thereof. The term 80 mesh under "Process Description" refers to the screen mesh used in printing.

TABLE 1

Example	Formulations used	Process Description	Fired Film Thickness in μm (mils)	Sheet Resistance in milliohms/sq	Resistivity of film (Ohm-Cm x 10^{-6})
1	BC - 12 Copper	80 mesh, pdf	50.8 (2.0)	0.60	3.05
2	BC - 12 Copper	80 mesh, 2 layers pdf, pdf	106.68 (4.2)	0.28	2.99
3	BC - 12 Copper	80 mesh, 3 layers pdf, pdf, pdf	160.02 (6.3)	0.16	2.56
4	BC - 12 Copper & PC - 2 Copper	80 mesh (BC - 12) bottom layer 80 mesh (PC - 2) top layer pdf, pdf	132.08 (5.2)	0.24	3.17

Wherein pdf indicates the operations printing, drying, and firing; and sheet resistance means resistance of a square form of the conductor and is measured by conventional methods.

The following examples in Tables 2 and 3 illustrate the thermal resistance values achieved using UTTFs according to the present invention. In examples A-G in Table 2, copper UTTFs were prepared using copper powder. The differences in each of examples A-G were the printing technique and the copper ink compositions used. These differences are described in Table 2 wherein "two-mil stencil" means a screen with a 50.8μm (2 mil) brass stencil was used, and "four-mil stencil" means a screen with a 101.6μm (4 mil)

brass stencil was used. In examples F & G, two layers of the UTTF formulations were each printed, dried and fired to achieve the final fired thicknesses.

TABLE 2

Example	Mesh Size	Fired Thickness	Average Thermal Resistance (°C/Watt)	Std. Dev (°C/Watt)
A	230*	--	2.506	0.469
B	80	--	2.360	0.146
C	80 + 2 Mil Stencil	--	2.297	0.164
D	230 + 230	--	2.140	0.092
E	80 + 2 Mil Stencil + 230	--	1.993	0.160
F	2 X (80 + 2 Mil Stencil)	--	1.968	0.143
G	2 X (80 + 4 Mil Stencil)	--	1.875	0.109

* Average thickness of 12.7 to 17.78 μm (0.5 to 0.7 mils) is obtained using a 325 mesh.

Silver UTTFs were prepared using commercially available DuPont 6160. The silver film printing processes are described in examples H-N of Table 3.

It should be noted that silver UTTFs can be made using a high-adhesion (solderable or non-solderable) film on the bottom, and a solderable (high or low adhesion) film on the top. A system that has been used in the laboratory included a silver conductor available at Delco Electronics Corporation as the bottom film, and a DuPont 6160 conductor as the top film. Other similar electrically-conductive thick film compositions, such as platinum-silver, may be used for UTTFs.

The disclosures in United States patent application no. 038,379, from which this application claims priority, and in the abstract accompanying this application are incorporated herein by reference.

TABLE 3

Example	Mesh Size	Fired Thickness	Average Thermal Resistance (°C/Watt)	Std. Dev (°C/Watt)
H	230*	--	2.170	0.091
I	80	--	2.088	0.156
J	80 + 2 Mil Stencil	--	1.949	0.145
K	230 + 230	--	2.038	0.075
L	80 + 2 Mil Stencil + 230	--	1.926	0.109
M	2 X (80 + 2 Mil Stencil)	--	1.881	0.079
N	2 X (80 + 4 Mil Stencil)	--	1.848	0.070

* Average thickness of 12.7 to 17.78 µm (0.5 to 0.7 mils) is obtained using a 325 mesh.

Claims

1. A micro-electronic device comprising: a heat-generating component (26;38;54); a solder layer (28;40;56) underlying said component; and a heat-conductive film (30;42;58,80) interposed between the solder

layer (28;40;56) and an alumina substrate (32;44;60), characterised in that said heat-conductive film is an ultra-thick thick film (30;42;58,80) having a thickness ranging from about 50.8µm (2 mils) to about 127µm (5 mils).

2. A micro-electronic device according to claim 1, in which the device further comprises a metal backplate (36;66) and a thermally-conductive adhesive (34;64) interposed between said backplate (36;66) and said alumina substrate (32;60).

3. A micro-electronic device according to claim 1, in which said ultra-thick thick film (30;42;58,80) comprises a metallic material selected from the group consisting of copper, silver, palladium-silver and platinum-silver.

4. A micro-electronic device according to claim 3, in which said ultra-thick thick film (30) comprises a first high-adhesion layer adhered to said alumina substrate (32) and prepared from a composition further comprising an inorganic binder, and a second high-solderability layer secured to said first layer and adjacent said solder layer (28), and said second layer being substantially free of inorganic binder.

5. A micro-electronic device according to claim 4, in which said metallic material consists of copper.

6. A micro-electronic device according to claim 1, in which the device also includes an ultra-thick thick film (46) having a thickness ranging from about 50.8µm (2 mils) to about 127µm (5 mils) underlying said alumina substrate (44); a solder layer (48) underlying the second ultra-thick thick film (46) and a heat-sink (50,52) underlying the second solder layer (48).

7. A micro-electronic device according to claim 6, in which said heat-sink (50) comprises a copper substrate underlying said second solder layer (48) and an aluminium backplate (52) adhered to said copper substrate (50).

8. A micro-electronic device according to claim 6, in which said first ultra-thick thick film (40) comprises a first high-adhesion layer adjacent to said alumina substrate (44) and prepared from a composition further comprising an inorganic binder, and a second high-solderability layer adjacent to said first solder layer (40) and being substantially free of inorganic binder; and in which said second ultra-thick thick film (46) comprises a first high-adhesion layer adjacent to said alumina substrate (44) and prepared from a composition further comprising an inorganic binder, and a second high-solderability layer adjacent to said second solder layer (48) and being substantially free of inorganic binder.

9. A micro-electronic device according to claim 6, in which each of said first and second ultra-thick thick films (42,46) are prepared from a material comprising copper.

10. A micro-electronic device according to claim 1, in which the heat-generating device is an integrated circuit chip (54); said alumina substrate (60) has a length and width substantially greater than that of the integrated circuit chip (54); there is an ultra-thick thick film (62) having a thickness ranging from about 50.8µm (2 mils) to about 127µm (5 mils) underlying said alumina substrate (60) and having a length and width slightly larger than that of the integrated circuit chip (54); there is a thermally-conductive adhesive layer (64) underlying said alumina substrate (60) and said second ultra-thick thick film (62); and there is a backplate (66) adhered to said adhesive layer (64).

11. A micro-electronic device according to claim 10, in which there is a wire (68) connected to an electronic component (54) on one end and having a foot on the other end bonded to an ultra-thick thick film (70) having a thickness ranging from about 12.7µm (0.5 mils) to about 76.2µm (3 mils), with said alumina substrate (60) underlying said ultra-thick thick film (70).

12. A micro-electronic device according to claim 10, in which said thermally-conductive adhesive layer (64) underlying said alumina substrate (60) has a length and width greater than that of the integrated circuit chip (54) and the ultra-thick thick film (62) is surrounded by the thermally-adhesive layer (64) so that the thermally-conductive adhesive layer (64) is relatively thin in the area under the integrated circuit chip (54) for improved heat transfer and the remaining portion of the thermally-conductive adhesive layer (64) is relatively thicker to provide stress-relief between the substrate (60) and the backplate (66).

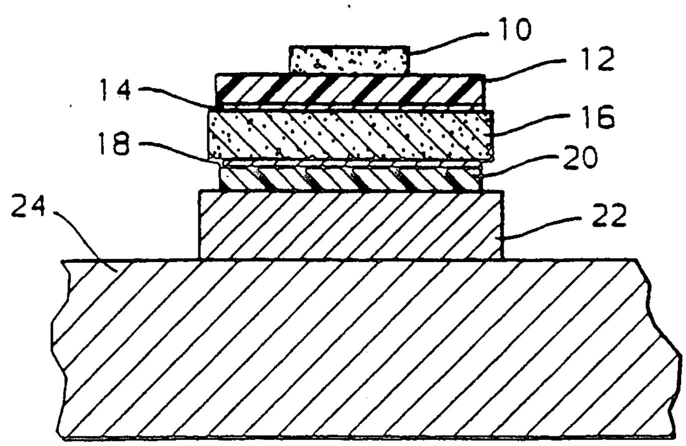

FIG. 1 PRIOR ART

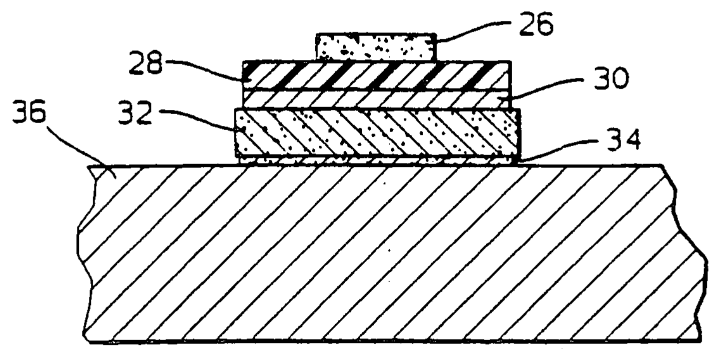

FIG. 2

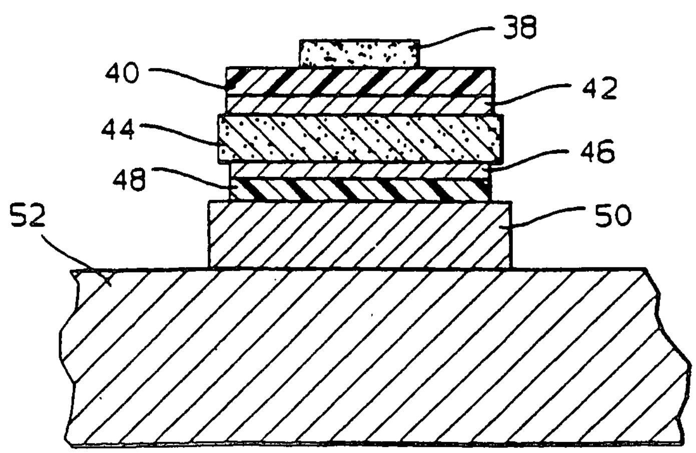

FIG. 3

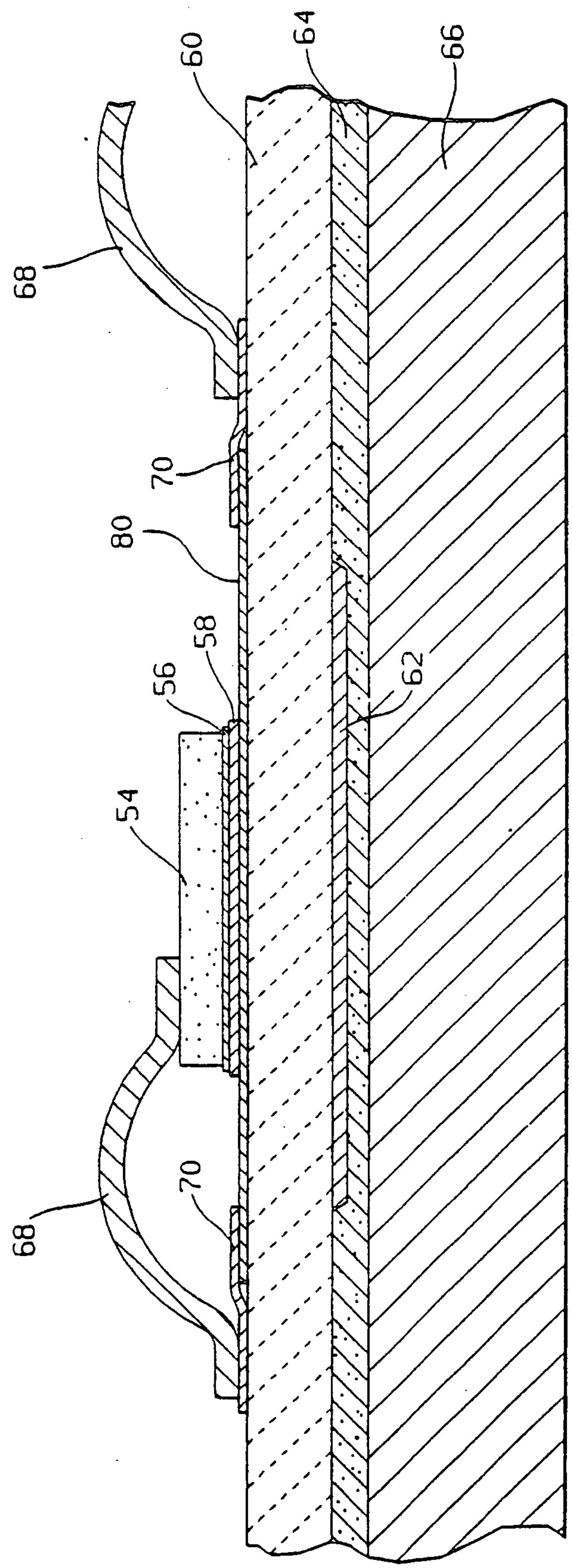

FIG. 4

European Patent Office

EUROPEAN SEARCH REPORT

Application Number
EP 94 20 0577

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.5)
X	EP-A-0 434 264 (WESTINGHOUSE ELECTRIC CORPORATION) * the whole document * ---	1-5	H01L23/373
X	FEINWERKTECHNIK + MESSTECHNIK vol. 98, no. 11 , November 1990 , MUENCHEN DE pages ZM198 - ZM204 W. MARTIN ET AL. 'DCB-Substrate für die Leistungselektronik - Eigenschaften und Anwendungen' * page ZM200, column 2, paragraph 3 - page ZM202, column 1, paragraph 3; figure 3 * ---	1,2,6,7, 9,10	
A	EP-A-0 468 475 (KABUSHIKI KAISHA TOSHIBA) * the whole document * ---	1-12	
A	EP-A-0 297 569 (SUMITOMO ELECTRIC INDUSTRIES) * abstract * ---	1-9	TECHNICAL FIELDS SEARCHED (Int.Cl.5)
A	EP-A-0 194 475 (OLIN) * the whole document * ---	1-9	H01L
A	EP-A-0 170 022 (IBM) * abstract; figures 1,4 * -----	10-12	

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	17 Jun 1994	Prohaska, G

CATEGORY OF CITED DOCUMENTS

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